Efficiency Studies of Quartz Radiators for the Mu2e Upstream Extinction Monitor

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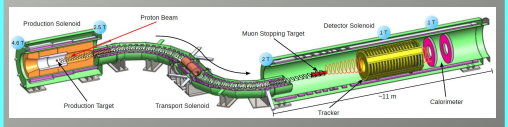
Abstract

Detailed knowledge on pulse characteristics, such as out of time beam is a requirement for many accelerator type experiments. In order to carry out sensitive experiments, such as the Muon to Electron (Mu2e) experiment, out of time beam must be measured at very stringent levels. The Upstream Extinction Monitor for the Mu2e experiment plans to employ a charge telescope composed of a series of quartz radiators attached to UV sensitive PMTs to statistically monitor beam scattering in the M4 beam line, allowing us to measure the ratio of beam between pulses to beam in pulses. A cosmic ray prototype was built using scintillators and a quartz radiator. Using C++, data acquisition and data analysis programs were developed to determine the efficiency of the quartz radiators oriented in two different ways to determine the optimal orientation.

Charged Lepton Flavor Violation (CLFV)

- Standard Model of particle physics requires that leptonic flavor numbers are to be preserved if and only if neutrinos were massless.
- Since neutrinos have a small nonzero mass, lepton flavor numbers are only approximate.
- This implies that the lepton conservation laws must hold for interactions containing charged leptons.
- Should be possible to observe rare decays such as $\mu N \rightarrow eN$.
- Such a process will provide evidence of CLFV, pointing to many new models of physics beyond the Standard Model.

Mu2E Experiment



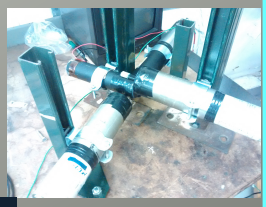
- Designed to measure the ratio of direct conversion of muons to electrons in the presence of a nucleus, with respect to the rate of typical muon capture on the nucleus,

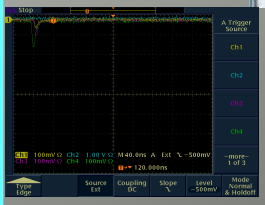
$$R_{\mu e} = \frac{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}{\mu^- + A(Z,N) \rightarrow \nu_\mu + A(Z-1,N)}$$

- Four orders of magnitude beyond SINDRUM II with $R_{\mu e} \approx 2.87 \times 10^{-17}$.
- 8 GeV proton beam pulsed at 0.6 MHz produces pions and muons on target.
- Low energy muons are captured in Al stopping target.
- Trajectories and energies of the electrons are then measured via the tracker and calorimeters.

Cosmic Muon Prototype

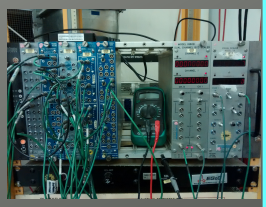
- Stands constructed with Unistrut metal framing.
- Mounted to stands and connected to PMTs are:
  - 3, 1cm x 1cm x 0.5cm scintillators (Chs 1, 3, & 4).
  - 1, 2cm x 2cm x 0.5cm quartz radiator (Ch 2)





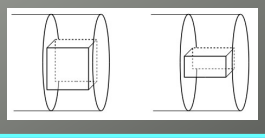
- Tektronix TDS3054B scope triggers on 3 scintillators.
- Stores triggered events to a file for data analysis.
- NIM electronics count number of coincidences through all 3 scintillators.

- LeCroy Research Systems NIMs used:
  - 623B Discriminator
  - 429 Fan In / Fan Out
  - 364AL Dual 4-Fold Logic Unit
  - 622 Quad 2-Fold Logic Unit
- Threshold on discriminator is set to about 30mV.
- Width on discriminator set to about 10ns
- Scintillator on Ch 3 is delayed by about 50ns to a separate counter to measure accidental rate.



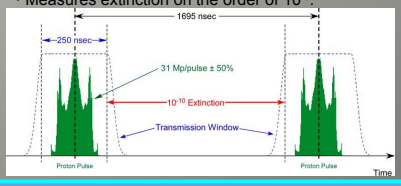
Quartz Radiator

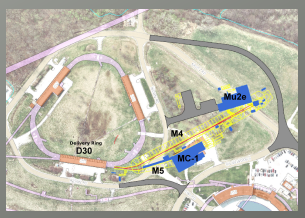
- Chosen over scintillators for three main reasons:
  - No intrinsic after pulses
  - Very fast response time
  - Blind to soft particles
- Relies on Cherenkov radiation to signal PMT.
- Rate of quadruple coincidences and accidental quadruple coincidences were collected with two different orientations of the quartz radiator:

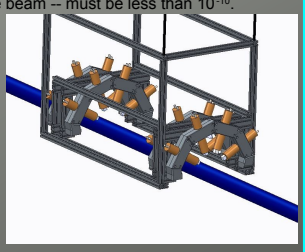


Extinction

- Ratio of beam between pulses to the beam contained in the pulses -- defined to be extinction of the beam -- must be less than 10^{-10}.
- Monitored in two stages:
  - Target Extinction Monitor (TEM):
    - Placed opposite of production target from proton beam.
    - Measures extinction on the order of 10^{-10}.
  - Upstream Extinction Monitor (UEM):
    - Placed in M4 beam line.
    - Measures extinction on the order of 10^{-5}.



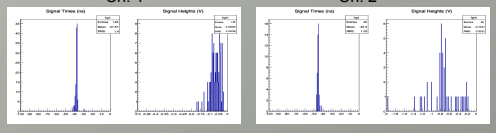




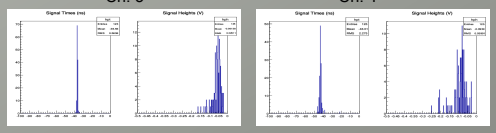
Results and Conclusion

Vertical Orientation:
- NIM counters registered 130 triggered events with 3 accidental over the course of about 40.5 hours.
- Data analysis program shows that out of 125 records, 45 records (36%) are a quadruple coincidence hits. Rate of 1.11 events/hour

Ch. 1 Ch. 2

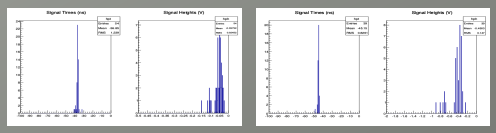


Ch. 3 Ch. 4

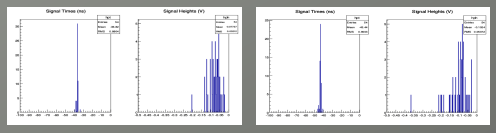


Horizontal Orientation:
- NIM counters registered 66 triggered events with 8 accidental over the course of about 26.3 hours.
- Data analysis program shows that out of 54 records, 39 records (72%) are a quadruple coincidence hits. Rate of 1.48 events/hour.

Ch. 1 Ch. 2



Ch. 3 Ch. 4



Although there appear to be more accidental coincidence rates associated with horizontal orientation, the rate of of real coincidences seem to have increased by a factor of 2 when switched to the horizontal orientation. Since the horizontal orientation has a wider cross sectional area, more internal reflection occurs from the Cherenkov radiation, so it is reasonable that the event rate would be higher for the horizontal orientation. These numbers are a very rough estimate. Both the geometry of the cosmic ray telescope and the energies associated with the particles contribute to the rate at which quadruple coincidence events occur. Since the numbers from the NIM counters don't agree with the number of records acquired by the program, the accidental coincidence rate is also a very rough estimate at best. For future work an improved version of the data acquisition program should be developed to account for accidental coincidences as well as real ones.

Acknowledgements

This work was supported by funds from the Illinois Accelerator Institute. Very special thanks to my mentor Eric Prebys for guidance, the Mu2e collaboration for suggestions and ideas.

August 2015

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